THE IMPORTANCE OF MIDDLE-LEVEL CONVERGENCE, EVAPORATION, MELTING, AND PRECIPITATION LOADING TO DAMAGING SURFACE WINDS

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Damaging surface winds are associated with bow echoes and rear inflow jets, and/or intense convective downdrafts/microbursts associated with multicellular or isolated severe pulse storms.

With pulse storms, differentiation of severe microburst-producing storms from ordinary cells can be difficult. Even with bow echoes, once a well-defined bow is observed, damaging winds likely are already occurring at the surface. Thus, the key is to "catch" or anticipate the development of these downbursts and bowing line segments even before well-defined structures are observed. The bow may be due to a rear inflow jet and/or a microburst which produces damage before any pronounced bowing signature appear.

There are several precursor factors that are strongly correlated to the development of damaging surface winds. These include 1) a high reflectivity core that initially begins at a higher altitude than most other storms; 2) strong, deep convergence at mid-levels in a storm; 3) a rapidly descending reflectivity core in a storm; and to a lesser degree 4) mid-altitude rotation; and 5) strong storm-top divergence. In addition, these processes are very important for enhancing the speed of the downdraft: 1) precipitation loading/drag; 2) evaporative cooling; and 3) phase change from ice to liquid (melting).

<u>High reflectivity core that initially begins at a higher altitude than most other storms</u>: This is indicative of a stronger updraft that has the ability to suspend more mass aloft for a longer period of time. These storms often are caused by boundary or cell intersections or along outflow boundaries where enhanced convergence is occurring. Thus, initial storms <u>may</u> be less of a severe threat than subsequent cells initiated along the outflow of the earlier, weakening storms. Look at the WSR-88D middle- and high-level layer maximum reflectivity product, all tilts, and vertical cross-sections to assess this parameter.

<u>Strong and deep convergence at mid-altitudes in the storm</u>: Mid-level convergence (as observed in storm-relative velocity data) appears to be a critical factor for both severe pulse storm and bow echo development. Convergence can be assessed using WSR-88D storm-relative velocity data typically between 15000-25000 feet (generally lower values for shallower storms and vice versa), i.e., anywhere from 2-6 km AGL. Within convergence areas, values of (**V_{in} + V_{out}**) (i.e., delta V) of **<u>50 kts or higher</u>** along the same radial generally are observed in those storms that produce surface microburst winds. Storms displaying significant delta V values at multiple levels are more likely to produce surface wind damage. Remember, however, that accurate view of the entire convergence field may not be identifiable given only radial winds, i.e., convergence may be occurring but is not fully detectable due to the orientation of the wind versus the radar beam, a limitation usually with storms moving perpendicular to the radar beam.

The convergence occurs at the updraft/downdraft interface in the storm, and usually is found either within the core of high reflectivity or along the leading edge of higher reflectivity values. With rear inflow jets, the convergence may be occurring between an elevated rear-to-front rear inflow jet (originating from the back side of the storm) and the updraft inflow air (originating in the near storm environment ahead of the storm). The convergence often precedes an increase in VIL by 1-3 volume scans. It also increases downdraft speed, especially if drier environmental air is entrained (see below). The convergence may or may not be easily observable for isolated pulse storms, but usually is observable for multicellular storms, including squall lines and bow echoes. In fact, detection of strong middle-level convergence within a portion of a squall line may be an early indication that a downburst may be imminent which could produce a bowing line segment (i.e., the incipient bow echo stage). In other words, a needed warning may be possible before any significant bowing structure is observed, as damaging winds already may be present at or near the surface. Once significant bowing begins, less middle-level convergence may be evident. Be sure to assess this parameter on the WSR-88D as much as possible.

<u>Rapidly descending reflectivity core</u> and <u>Precipitation loading/drag</u>: These factors often play a central role in forcing an intense downward vertical acceleration. Sometimes, these phenomena are associated with warming/collapsing cloud tops on satellite imagery (although the temporal resolution of current imagery is not enough to help in real-time warning situations). The larger the reflectivity core and the more coherent the descending mass, the greater the amount of air that will be dragged downward. The drag effect can be substantial given a large water content in the cloud causing gusty surface winds. If the descending mass falls through a sub-cloud layer characterized by low relative humidity values and/or descend from a relatively high cloud base, this core is more likely to be associated with a surface microburst due to evaporation and subsequent cooling in the sub-cloud layer. Thus, evaporation as well as melting and mid-level convergence also may be required to produce intense microbursts. These factors can be evaluated through WSR-88D layer maximum reflectivity, all tilts, and vertical reflectivity cross-section products.

Evaporative cooling: Negative buoyancy and the downdraft strength are increased through evaporation of liquid water into unsaturated air. The evaporation, which produces cooling due to the latent heat of vaporization, occurs when relatively dry mid-level air (roughly in the 3-7 km layer) is entrained into the thunderstorm, or when precipitation falls into unsaturated air below cloud base. However, if dry air is entrained into the precipitation core at high levels, little evaporative cooling will occur since the air is too cold. As the core descends into warmer air, the effects of evaporative cooling become much more important. Thus, dry air at 700 mb may be more important than at 500 mb. The presence of dry/unsaturated environmental air, and subsequent evaporative cooling after entrainment into the thunderstorm core can have a substantial effect on downdraft strength. It should be noted, however, that significant evaporation can take place without altering the general appearance of a radar echo, since the smallest drops evaporate first and most efficiency. The small drops do not contribute significantly to overall reflectivity since reflectivity is proportional to the sixth power of drop size.

Phase change from ice to liquid (melting): Negative buoyancy and downdraft strength also can be increased though a phase change from ice to liquid (i.e., melting) due to the latent heat of fusion. Therefore, a reflectivity core extending to a high altitude in the storm (well above the freezing level), suggests that there may be significant melting as the core descends toward the ground, thereby complementing the precipitation loading/drag effect. The cooling due to phase changes in water during descent (melting and evaporation) can play a significant role in accelerating the downdraft toward the ground.

Mid-altitude rotation: The presence of cyclonic rotation within a storm's updraft suggests the cell's ability to carry precipitation to higher altitudes within the storm, and for separation of the updraft from the downdraft. A rotating storm obviously must be monitored more closely for its ability to produce a downburst. However, rotation, while important, appears to be a lesser precursor of a damaging downburst than other factors described above. Mid-altitude rotation is not necessary for downburst production.

Strong storm-top divergence: This factor again appears to be important to surface downburst production, but to a lesser degree than other factors listed above. Strong storm-top divergence in storm-relative velocity data suggests an enhanced updraft speed with compensating strong storm-top ventilation. Thus, the strong updraft would have the potential to lift a significant reflectivity core to high levels within the storm, well above the freezing level.

WSR-88D products/signatures useful for identifying severe pulse thunderstorms: A very effective strategy is the use of base reflectivity at low-levels in conjunction with composite reflectivity and the "mid" (24000-33000 ft) and "high" (33000-60000 ft) layer composite reflectivity maximum (LRM) products. Also, the use of “All Tilts” allows one to quickly view all reflectivity elevation angles from the same volume scan, thus allowing assessment of storm core strength, depth, and tilt. Reflectivity values of > 50 dBZ in the "high" layer with low returns at the 0.5 elevation angle suggest a developing intense cell that may be capable of a microburst once the core begins its descent, given other favorable environmental parameters. Do not wait until the core reaches the 0.5 level. Also, reflectivity values > 65 dBZ (pink) anywhere within the storm and/or values > 55 dBZ above 30000 ft (highly dependent on storm top) may well be associated with a downburst and/or large hail at the surface, assuming the freezing level and wet bulb zero heights are not too high. VIL also is useful but an increase in VIL likely may be associated with a descending reflectivity core, so any warning lead time would be minimal. LRM "mid" and "high" products appear to be better than VIL; a loop of LRM is quite useful. Storm-relative velocity at various elevation angles should be used to assess mid-level convergence and rotation.

For additional information, refer to the Flow Chart to Evaluate Wet Microburst and Large Hail Potential from Pulse or Multicellular Thunderstorms.